Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

CANMET
Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

EXPLANATORY NOTES FOR THE MULTIPLE CUTOFF EVALUATION METHOD

A. Fustos, P. Eng.
Mine Evaluation Group

December 1982

This document is an unedited interim report prepared primarily for circulation and internal reporting purposes. It does not represent a final expression of the opinion of the Canada Centre for Mineral and Energy Technology (CANMET)

Ce document est un rapport provisoire non-révisé et rédigé principalement pour fin de diffusion et de documentation interne. Il ne représente nullement l'expression définitive de l'opinion du Centre canadien de la technologie des minéraux et de l'énergie (CANMET)

ENERGY RESEARCH PROGRAM
MINING RESEARCH LABORATORIES
DIVISION REPORT ERP/MRL 82-140(TR)

MICROMEDIA

CONTENTS

	Page
SUMMARY	1
PURPOSE	1
THE EVALUATING PROCEDURE	4
CLASSIFICATION OF RESOURCES	8
EXTRAPOLATION FACTORS	10

SUMMARY

Forecasting future economic conditions is an unrewarding task, which has sapped the ingenuity of many and caused bitter disillusions when the predictions of even short-range forecasts failed to materialize. Mining suffers from the effects of unfulfilled expectations more than any other type of business activity because by nature it is non-elastic and the duration of its operation extends over decades. It requires large capital investment whose returns will be spread out over a long time. The exploitation of orebodies cannot be speeded up, or slowed down once it is initiated. Consequently, rapid adjustments to the vagaries of the economic climate are well nigh impossible. In order to create a tool, which could help to outline possible alternatives for a mining enterprise in different future economic scenarios a method was devised whose application could reveal by simple and rapid calculations how the value of the dominant asset of the mine - its orebody - will change in the context of future unforeseen metal prices. The method is the MULTIPLE CUTOFF EVALUATION METHOD.

PURPOSE

Mining, the profitable exploitation of orebodies, is an activity whose duration is measured in decades. From the date of the corporate decision, inaugurating the establishment of a mining enterprise, to the final depletion of the orebody, exploited by the operating mine, the enterprise will enjoy and suffer the effects of many changing economic cycles. While the dominant and often sole asset of the mine, its orebody, will diminish at a steady rate which cannot be accelerated or slowed significantly in the short term, the value of the same orebody could change rapidly due to changes of mineral commodity prices, governed by the fluctuations of world-wide economic conditions. Commodity price changes often have greater influence on the size and value of orebodies than their steady exploitation rate.

The estimation of the size and value of an orebody is a major geological and mining engineering project. It is usually done before the actual exploitation of the orebody begins because corporate capital investment decisions as well as the planning of the mining and mineral processing techniques, which the future operating mine will use, will be based on the results

of the ore reserve estimation. Furthermore, the preplanned operating procedures, once initiated and operating, do not lend themselves to rapid and drastic changes. These circumstances restrict the ore reserve estimation project, as it is usually executed in the mining industry, to an in-advance defined benchmark, an economic cutoff grade, which satisfies the fundamental profitability requirement of the mining enterprise in the economic scenario, prevalent at the time of corporate decision making.

Once the economic cutoff grade is established, the estimation of the size and value of the orebody, i.e., the ore reserve calculation, can commence to prepare an ore reserve inventory. The ore reserve inventory will be based on facts and assumptions. A single entity, the accumulated sampling data base, will contain all the facts. The assumptions will be based on theoretical knowledge and practical experience accumulated from investigations of both previously evaluated similar orebodies and the exploration of the actually examined orebody, as well as on the tenets of the chosen reserve calculation method. It is vital to keep in mind that only the sampling data base is factual; the choice of the calculation method and the application of its tenets to the actual calculation is based on assumptions, rooted in the personal judgement of the calculator.

While the validity of the factual part of this dual foundation is objectively provable, the validity of the applied assumptions will remain forever debatable. Since the results of the ore reserve calculations are the fruits of mating provable facts with debatable assumptions, the dependability of the calculated ore reserve inventory will remain inherently unprovable at least until the ultimate depletion of the orebody and in many cases even after that time. In contrast with the indefinite accuracy of the calculated ore reserve inventory, its precision can be improved in two ways. One can apply a more sophisticated calculating method and/or one can increase the size of the utilized sampling data base. Both types of improvements will increase the cost and time requirements of the ore reserve calculation project. It is worthy to note here that the customary division of calculated ore reserve inventories into such categories as inferred, indicated and measured or possible, probable and proven, reflect the subjectively assigned and qualitative precision levels of these categories. About their accuracy these names can say nothing, because these precision levels are primarily derived from the essentially subjective assumptions, accepted before the beginning of the cal-

culating exercise and only secondarily from the utilized factual sampling data base. Indeed it is significant that the very first assumption, the chosen economic cutoff grade, truncates the sampling data base because only that part of the latter will be utilized in the ore reserve calculations which satisfies the preconditions requested by the cutoff grade. The part of the sampling data base which falls short of the requirements of the cutoff grade will be ignored generally in the calculation procedure, although it is an integral part of the factually known information of the orebody, because it fails to satisfy an envisaged economic scenario.

Despite all of the above said considerations ore reserve calculation results, produced within the confines of a predetermined cutoff grade, play a fundamental and vital role in the life of the mining enterprise, because all planning of the mining and ore processing methods, as well as the production rates, will be based upon them. But, since they hinge on a chosen singular economic scenario, they lose a large degree of their usefulness when the profitability of the mining enterprise is considered in the context of a macro-economic configuration, into which the originally visualized economic scenario does not fit well. Drastic changes in mineral commodity prices, in labour, equipment and energy costs or changes in the cost of capital borrowing could make the chosen economic cutoff grade unrealistic and unsatisfactory. If such situations develop, the results of the ore reserve calculation, essentially a quantitative statement about the size and value of the orebody, could lose their validity. Then a new cutoff grade will be needed. In terms of the new cutoff grade, new ore reserve calculations need to be done and the results of these new calculations will decide whether the mine is still profitable, its profitability has increased or, due to the drastical deterioration of the economic climate, the mine has become a liability to its owners.

An ore reserve calculation project is a time consuming exercise, whose costs rise directly with the increase in the sophistication of the applied calculating method. Consideration of this fact will negate the feasibility of a solution which advocates the preparation of several parallel ore reserve calculations, satisfying the requirements of a series of alternative benchmark cutoff grades. Yet, if not for actual mine and production planning, at least for corporate decision making or for economic forecasting, both on corporate and governmental levels, it is advisable and often necessary to have a series of alternative size and value estimations about the same orebody.

The MULTIPLE CUTOFF EVALUATION METHOD was devised to fill such needs and by-pass the costly and time consuming alternative of preparing several parallel ore reserve calculations independent from each other. The devised method has the following advantages:

1. Its sole basis of ore reserve calculation is the existing sampling data base, the only objectively derived fact known about the investigated orebody.
2. The method does not apply any assumptions, derived from generalizations or arrived at by deductive reasoning, to the calculative procedure.
3. The ore reserve calculation is a rapidly preparable simple exercise, following closely the pattern of methodologies, routinely used in industrial, commercial, financial and economical decision making and forecasting.
4. The level of the precision of the ore reserve calculation results will be a function of a single factor, the size of the utilized sampling data base. Subjective assumptions, whose correctness are inherently unverifiable, will not influence its precision level, consequently they should not trigger a sense of false security in the user of results.

It is only proper to point out that the results, produced by the Multiple Cutoff Evaluation Method, cannot form the basis of systematic mine planning or production scheduling. They are not intended to play such a role.

THE EVALUATING PROCEDURE

Ore reserve evaluation methods use the sampling data, derived from the exploration and development of the to-be-evaluated orebody, as the basis of their calculations. Ore tonnage, average grade and total metal content of the evaluated orebody will be calculated from the sampling data.

With the exception of a few highly complicated relatively new approaches, which require specialized skill and computers with large memory capacities, every ore reserve evaluation method starts with the selection of a definite cutoff grade. The cutoff grade will divide the sampling data into two parts. One which satisfies the economic restrains imposed by the predetermined cutoff grade and another which falls short of the requirement. Traditional ore reserve calculation methods will use only the first part of the data base and will ignore the second, consequently their final results will

offer only a single perspective about the evaluated orebody, the one which satisfies the economic requirements of the chosen cutoff grade. The MULTIPLE CUTOFF EVALUATION METHOD does not use any predetermined cutoff grade. It produces results in the form of simple linear functions. The user of its results can calculate any ore tonnage, average grade and metal content of the evaluated orebody, which satisfies any contemplated cutoff grade, by solving two linear equations, chosen by him from an offered selection of three.

The MULTIPLE CUTOFF EVALUATION METHOD is unique in the sense that it totally concentrates on the sampling data until the last step of the calculation. It uses the sampling data as a model of the evaluated orebody, derives the natural rate of change of ore tonnage, of average grade and of metal content in terms of a series of regularly increasing lower limiting grades and expresses the three rates of change as linear functions. The user of the results simply substitutes the cutoff grade, which he choses, as a lower limiting grade as the independent term in any two linear equations of the three and the solutions will be the corresponding answers to the chosen cutoff grade. The third answer is calculated from the first two by simple arithmetic.

When the required tonnage, average grades and metal content, corresponding to a chosen cutoff grade, in the sample data are established, with a few simple operations they can be extrapolated over the entire orebody, or any part of it, and the three quantities will then have the same meaning in terms of the latter. However, the extrapolated figures will be partially based on the acceptance of an assumption, i.e. that the sampling data is a true representative of the orebody from which it was collected. The validity of this assumption is verifiable with various statistical hypothesis testing techniques.

As a first step, the logs, describing the core, are computer coded according to the coding procedures, developed by MEG. The coded data file will contain the quantitative description of every core segment in terms of length, metal content (assay) and each segments' actual location with its attitude in a three-dimensional space. The coded data is subsequently keypunched and transferred to a computer tape which is stored in the EMR computer. In essence, the core, a REPRESENTATIVE SAMPLE from the surmised orebody, in this way becomes a computer-manipulable model of the same. The MULTIPLE CUTOFF EVALUATION METHOD is totally concentrated on this model. It does

not consider any subjective assumptions, like the speculative lateral extent, attitude or genetic style of the UNKNOWN orebody. In a sense it is analogous to the analysis of a bulk ore sample by the extractive metallurgist, who uses the results of laboratory experiments on the bulk sample to design the mill which will extract the valuable component from the orebody during the entire time of its active mining. This is a cardinal difference between the MULTIPLE CUTOFF EVALUATION METHOD and any other ore reserve estimation method.

The computer-manipulable model, the data file, is subjected to a sequence of computer programs some of which were designed by MEG staff, some other which are "canned" programs available in the EMR computer.

The first program uniformizes the individual drillholes in the model by transforming all of them into their vertical projection. This is done to eliminate any possible random or systematic emphasis or trifling of any part of the file which could have been caused by the inevitable wandering of the drillholes during their drilling. The next programs used in sequence filter out parts of the data file according to the assay values of the individual sample segments. These programs are analogous to the sieve analysis of mineral aggregates where a sample is shaken through a sequence of sieves with regularly diminishing sieve openings to establish the quantitative grain-size distribution of the sampled aggregate. The pre-arranged, regularly increasing assay values are lower limiting values, playing the same role as the regularly diminishing sieve opening sizes in the sieve analysis. The programs break down the total data file into fractions in terms of the regularly increased lower limiting assay values. Using these values as independent (X) variables, three sequences of dependent (Y) variables are established:

(a) Sum of the vertical length of all core segments having equal or greater assay value than each successive lower limiting assay value.

(b) Weighted (by segment length) average assay value of the sum of the fraction of the file above each successive lower limiting assay value.

(c) Sum of the products gained by the multiplication of all individual core segment lengths, above each successive lower limiting assay value, with their respective individual assay values.

The first dependent variable is the "ore" content of each fraction of the total sample, described quantitatively in linear or "length" terms, the second dependent variable is the average grade of each, successively richer, fraction of the total sample, and the third dependent variable is the absolute amount of the valuable content of each, successively richer, fraction of the total sample in quantitative "weight". In geological consideration, the first dependent variable is a compound variable influenced by two factors: the receptivity of the hostrock toward the valuable mineral component at the time of the genesis of the orebody (strictly speaking, only the actual drill core) and the total amount of valuable mineral component, deposited at the time of ore genesis, in the hostrock. The second dependent variable is also a compound variable, influenced by the same two factors as the first dependent variable. Finally, the third dependent variable is a simple one, a consequence of a single factor, namely the total amount of valuable mineral component deposited during the time of ore genesis in each individual assayed core segment.

The computer programs, which will treat the results of the above described programs, are essentially correlation and linear regression analyses. In succession, all three sequences of dependent variables are linearly correlated with the sequence of the independent variable and if the correlation coefficient (r) is high enough, linear regression analyses are carried out. The results of this step, graphically sloping lines and analytically first degree algebraic equations, describe the nature of the mineralization in the REPRESENTATIVE SAMPLE quantitatively. With the help of the equations, the amount of ore, its average assay value, and the amount of valuable mineral content present in the sample above any, arbitrarily chosen, lower limiting assay value (cutoff grade) can be calculated. The calculated amounts are called GEOLOGICAL RESOURCES. These quantities describe the natural state of the sample without any consideration of its mineability.

The next step of the MULTIPLE CUTOFF EVALUATION METHOD prepares the data file for evaluation with consideration of an assumed or practised mining technology of the orebody. The preparation utilizes a routinely used program of MEG, named COMPOS, which transforms the raw drilling data into a sequence of economic intersections. The program calculates these intersections in terms of mining cutoff grades and minimum mining thicknesses. The sequence of core segments of the original drilling file will be transformed into

sequences of economically and technologically mineable segments. The COMPOS program is applied repetitively to the data file, using the same minimum mining thickness but regularly increasing mining cutoff grades, to establish inventories of mineable ore for each.

A final step of the calculative sequence will run correlation and regression analyses on the COMPOS-established mineable ore inventories to establish quantitatively the MINEABLE RESOURCES present in the REPRESENTATIVE SAMPLE. The results of these correlation and regression analyses will be tabulated and utilized in the same way as those arrived at by the calculation of the GEOLOGICAL RESOURCES.

CLASSIFICATION OF RESOURCES

The MULTIPLE CUTOFF EVALUATION METHOD assesses the REPRESENTATIVE SAMPLE, which usually consists solely of the drill core, extracted from the assumed orebody by diamond drilling. The REPRESENTATIVE SAMPLE, not being the entire orebody, demands a classification of the resources contaned in it which is different from the usual resource classification system utilized in reserve estimations of the entire orebodies.

The classification of the resource within the REPRESENTATIVE SAMPLE consists of the:

(a) Geological Resource Category, and
(b) Mineable Resource Category (or categories).

The Geological Resource category includes all assayed core segments of the diamond drilling. Excluded are nonassayed parts of the drill core and those assayed core segments whose valuable mineral content is detectable but not measureable by the applied assaying method. In the latter cases, the assay value is usually called a "trace", signifying that the presence of the valuable mineral component was detected but its quantity cannot be measured, being below the lower measuring limit of the applied assaying method. While the results of the Geological Resource evaluation are not directly utilizable for economic studies, they contribute in several ways to the knowledge of the investigated REPRESENTATIVE SAMPLE directly and to the knowledge of the sampled orebody indirectly.

The evaluation of the Geological Resources of the data file deals with the entire sampling data and considers it in its entirety, without application of an artificial truncation which could cause introduction of inadvertent bias. The maximum amount of available sampling is used in this context and the resulting regression equations will describe the natural state of affairs which were established by the mineralization process during the genesis of the REPRESENTATIVE SAMPLE, which was assumedly the same for the entire (at this stage only surmised) orebody too. This is by itself already a great advantage of the present method over any other evaluation method, because other methods, even if they throw light on the mineralization process in the investigated orebody, do it only after the completion of the evaluation procedure. Their final deductions in this aspect will be inevitably influenced by various more or less subjective geometric or statistical assumptions which were applied during the evaluation. It is a plausible hypothesis that the nature of the mineralization process, or in other words the genesis of the orebody, is quantitatively described by the results of the three types of regression analyses. Consequently these results are just as singularly typical of the investigated orebody as fingerprints are of a human being.

The Mineable Resource category, or categories, consist of the results of the MULTIPLE CUTOFF EVALUATION after the evaluation has been done on an interpreted base file. These results reflect the state of the resources with consideration of their mineability. The mineability consideration is introduced into the evaluation by conversion of the basic, uninterpreted data file to an interpreted one. With the utilization of MEG's COMPOS program the individual core segments are converted into composites whose lengths equal or exceed a predetermined minimum mining thickness and minimum average grade. With the minimum mining thickness parameter kept constant and the acceptable minimum average grade (cutoff grade) gradually increasing, the basic data file is treated repetitively to establish inventory files of mineable resources. The total contents of the inventory files will subsequently become the individual dependent variables in the following correlation and regression analyses, in which the role of the independent variable wll be assigned to the acceptable minimum average or cutoff grades utilized in the repetitive COMPOS program treatment of the basic data file. Changing the minimum acceptable mining thickness parameter to an other value and repeating the COMPOS program treatment of the basic data file, as well as the final correlation and regres-

sion analyses, will produce results which show the state of the resources in the REPRESENTATIVE SAMPLE in context of a different mining technology.

In the present evaluation two mining technologies were considered. A traditional on-the-dip stoping method, using jack-leg drills and slushers and requiring a minimum of six feet vertical mining thickness, and a mechanized mining method, stoping parallel or convergent to the strike, utilizing low profile jumbo drills with LHD vehicles. For the second case a minimum vertical mining thickness of twelve feet was assigned.

EXTRAPOLATION FACTORS

The MULTIPLE CUTOFF EVALUATION METHOD is designed to calculate the resource status of the REPRESENTATIVE SAMPLE but the ultimate goal of any evaluation method is to do the same for the entire orebody. Consequently, the results of the presently used method needed to be extrapolated over the entire unknown mineralized volume of rock. As it was mentioned before, this step requires the acceptance of the assumption that the sampling data is an unbiassed representative of the orebody.

To expand in practice the results of the study on the REPRESENTATIVE SAMPLE over the entire orebody demanded the development of a logical extrapolation factor, which will make the extrapolation procedure a simple arithmetic calculation. There are two types of extrapolation factors in the exercise. Of the two, the first is not plainly expressed, while the other is explicit and visible on every quantitative resource statement table.

The first, implicit, extrapolation factor was devised merely for the purpose of facilitating the arithmetical operations connected with the utilization of the regression equations. It converts directly the measured lengths along the basic data file into tonnage and with its help the calculated valuable mineral content for each length fraction is expressed directly in weight units. The conversion is the consequence of expansion of the actual horizontal cross-sectional area of the drill core over a horizontal area which, multiplied with unit length, will give the in situ volume of one ton of ore.

The explicit extrapolation factor is calculated by the following formula:

$$(A/N) \div T.f.$$

where A = area, over which the result of the regression equation is extrapolated

N = number of the drillholes participating in the regression analysis data

T.f. = tonnage factor.

The expression A/N indicates that all participating drillholes are given equal influence area.

The areas, over which the results of the regression equation-corresponding to each increasing lower limiting grade - are extrapolated, are measured from minimum accumulation contour maps. The minimum accumulation contour maps are prepared according to the following logic:

The drillholes, participating in the data file, are plotted on a drill map of the evaluated orebody according to their actual location, i.e., by their latitudes and departures. To each hole a sequence of accumulation data is printed out. The individual accumulations are the products of the specified minimum mining thickness times the average grade of the existing COMPOS intersections in the respective hole, corresponding to the regularly increasing lower limiting grades which participated in the regresssion analysis data. The same lower limiting grades are multiplied by the predetermined minimum mining thickness. The results of these latter multiplications are the respective contour line values. The drill maps are then contoured according to the relationship between the actual and minimum accumulation at each hole.

The area, enclosed by each contour line is calculated and divided by the number of drillholes within its borders. The result of this division is further divided by the tonnage factor. The final result is the extrapolation factor.

The extrapolated reserves are classified according to the average influence distance, implicit in the extrapolation factor. Explicitly it is one half of the square root of the area per drillhole. If this distance is 100 ft or less the extrapolated ore can be safely classified as MEASURED. If the average influence distance is three to four times larger, the extrapolated areas will be classified as INDICATED if the drilling within their limits is on a quasi-regular grid.

INFERRED resources are extrapolated over undrilled areas. In this case the total undrilled area is divided by the number of drillholes in the sampling data file which have at least one COMPOS intersection whose accumula-

tion value is equal or greater than the accumulation value produced by the multiplication of the respective lower limiting grade and the postulated minimum mining thickness.